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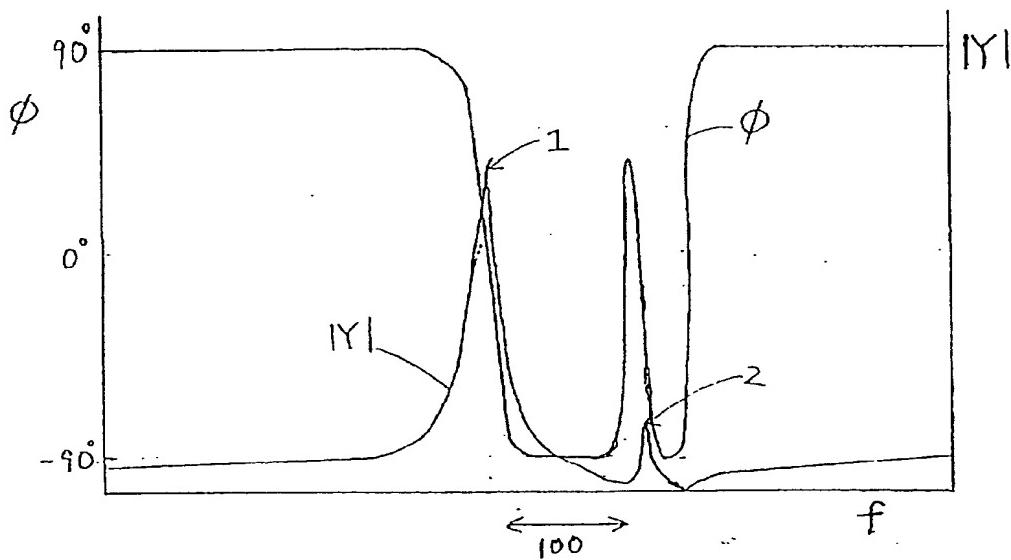
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(54) Ultrasonic motor and electronic appliance having same

(57) An ultrasonic motor is provided that is improved in reliability of a self-oscillator circuit constituted by the ultrasonic motor itself and high in efficiency. In a case of driving with one standing wave, the resonant point of a vibration mode used for driving is made lower than a

resonant point of another vibration mode that is same in form as this vibration mode but different in node position. Furthermore, oscillation is caused between two resonant points. Where using two standing waves, oscillation is caused at a higher frequency than any of the two resonant points.

FIG. 1



**Description**

**[0001]** The present invention relates generally to an ultrasonic motor having a vibrator having a piezoelectric element to vibrate for frictionally driving a moving member, and to an electronic appliance using such an ultrasonic motor. More particularly, the invention relates to an ultrasonic motor to be driven through self-oscillation by utilizing the ultrasonic motor as a vibrator.

**[0002]** In recent years, attention has been drawn to ultrasonic motors being used as actuators based on a new principle in various electronic appliances. Their applications have been attempted for camera auto-focus drive and other various fields. The ultrasonic motor generally adopts a separately excited drive scheme involving a frequency signal, created by an external oscillator circuit, which is applied to a piezoelectric element, to cause oscillation mode on a vibrator having the piezoelectric element. However, the separately excited drive scheme has the disadvantage of a complicated circuit configuration. In place of the separately excited drive scheme, a self-oscillation drive scheme has been tried and placed into practical use. In this case, an ultrasonic motor is utilized as a vibrator to cause oscillation due to resonance of the vibrator. The utilization of such a circuit contributes to size reduction and simplification of the circuit and ultimately reducing the size and cost for an apparatus on which a drive circuit is to be mounted.

**[0003]** However, the self-oscillation drive scheme involves anxiety which is often encountered because of unstable oscillation despite its feature of circuit size reduction and simplification, through the use of a reduced number of components. The self-oscillator circuit structurally utilizes the resonance of a vibrator as a mechanical filter, thereby amplifying only a particular frequency of signals for sustaining oscillation. However, the vibrator has a plurality of natural oscillation frequencies existing thereon. This might result in a fear of abnormal oscillation, which oscillation occurs at a resonant point including a different vibration mode from a target vibration mode. Such abnormal oscillation is ready to occur where other vibration modes are present in the vicinity of the target vibration mode. Meanwhile, the performance of an ultrasonic motor, such as rotation speed and torque, is largely dependent upon the drive frequency. For the self-oscillation drive scheme, the frequency is given by oscillation caused due to the vibrator and circuit with circuit elements. This results in the possibility that the frequency will be changed and hence a change in motor performance. Particularly, where self-oscillation driving is caused by utilizing a plurality of different vibration modes, the overall or overlapped resonant characteristic is complicated and ready to cause oscillation frequency change and hence abnormal oscillation because of differences in resonant frequency and characteristics between the different vibration modes.

**[0004]** According to the present invention, there is provided an ultrasonic motor having a vibrator having a

piezoelectric element to be vibrated to fractionally drive a moving member, the ultrasonic motor is characterised in that:

5       the vibrator has a first resonant point, and a second resonant point that is same in form as vibration mode to occur on the vibrator as the first resonant point but different in position of a node, wherein the second resonant point is higher in resonant frequency than the first resonant point.

**[0005]** The present invention relates to drive in an ultrasonic motor by a self-oscillation drive circuit. In securing oscillation stability, self-oscillation is caused using a frequency range in which one only is operable of a plurality of resonant points. For example, where an unwanted resonant point exists in the vicinity of a target resonant point, the unwanted resonant point is raised higher than a resonant point possessed by a vibration mode to be used to operate the ultrasonic motor. Due to this, the effect of unwanted vibration mode is suppressed as low as possible. Furthermore, self-oscillation is caused using a frequency range where phase change occurs only at the target resonant point. Particularly where a second resonant point exists between a first resonant point and an anti-resonant point thereof, resonance is caused between the first resonant point and the second resonant point. Meanwhile, where the ultrasonic motor is driven using a plurality of different resonant points, self-oscillation driving is made at a higher frequency than any of these resonant points.

Fig. 1 is a figure showing a frequency vs. admittance characteristic of a vibrator of an ultrasonic motor of the present invention;  
 Fig. 2 is a sectional view showing a structure of an ultrasonic motor of the invention;  
 Figs. 3A to 3D are figures showing a driving principle of the ultrasonic motor of the invention;  
 Fig. 4 is a figure showing an example of a drive circuit of the ultrasonic motor of the invention;  
 Fig. 5 is a figure showing another example of a drive circuit of the ultrasonic motor of the invention;  
 Figs. 6A to 6C are figures showing another driving principle of the ultrasonic motor of the invention;  
 Fig. 7 is a figure showing another example of a frequency vs. admittance characteristic of a vibrator of an ultrasonic motor of the invention;  
 Fig. 8 is a figure showing a frequency vs. admittance characteristic of a vibrator for explaining an effect of the ultrasonic motor of the present;  
 Fig. 9 is a figure showing a driving principle in a case that a rectangular plate vibrator is used in the ultrasonic motor of the invention; and  
 Fig. 10 is a block diagram showing an example that the ultrasonic motor of the invention is applied to an electronic appliance.

**[0006]** Embodiments to which the present invention is applied will be described in detail with reference to Fig. 1 to Fig. 9.

**[0007]** Referring to Fig. 1, a frequency vs. admittance characteristic is shown to explain the oscillation frequency of an ultrasonic motor to which the invention is applied.

**[0008]** Fig. 2 depicts a structure of the ultrasonic motor 3 as an embodiment of the invention, while Fig. 3 illustrates an operating principle of the ultrasonic motor 3. First explained is an operating principle of a ultrasonic motor according to the invention. In Fig. 2, an vibrator 6 in a disk form is supported on a center shaft 10 having a center fixed by a support plate 9. The vibrator 6 has a first surface bonded with a piezoelectric element 7 and a second surface provided with protrusions 6a to magnify vibration displacement of the vibrator 6 and give a rotational force to a moving member 8. The moving member 8 has at a center, a bearing 5 having a center guided by the center shaft 10. The bearing 5 has an inner race pressurized by a spring member 4 to provide a contact pressure between the protrusions 6a of the vibrator 6 and a friction member 8b of the moving member 8. Vibration waves caused on the vibrator 6 due to a piezoelectric effect of the piezoelectric element 7 are converted into a rotational force to the moving member 8 through a friction force.

**[0009]** Figs. 3A to 3D shows a detailed operating principle. The piezoelectric element 7 bonded on the piezoelectric element 6 is circumferentially divided by a quarter wavelength so that polarization can be made in alternate directions. Electrode patterns are alternately electrically shorted to constitute two groups of electrode patterns shown respective of which are shown by hatched areas 12a and non-hatched areas 12b. The vibrator and the piezoelectric element are bonded together such that the protrusions 6a of the vibrator 6 position just on respective boundaries of an electrode pattern. An electrode 12c is provided entirely on the bonding surface.

**[0010]** When a signal with a predetermined frequency is applied to the pattern group 12a, a standing wave is caused on the vibrator 6 as shown in Fig. 3C. Thereupon, the projections 6a raised incline to right to cause the moving member 8 in contact therewith to move rightward. The application of a signal to the non-hatched pattern group 12b causes a standing wave as shown in Fig. 3D, moving the moving member leftward this time.

**[0011]** The use of the piezoelectric element 7 of the present embodiment causes a standing wave having circumferentially three waves. Because the number of radial nodes differs depending on a frequency, the projections 6a are preferably provided at points where the amplitude is maximum with respect to a radial direction in an oscillated vibration mode.

**[0012]** Fig. 4 shows a drive circuit 13 to the ultrasonic motor using a Colpitts self-oscillator circuit. The Colpitts oscillating circuit constitutes an oscillator circuit by utili-

zation that the piezoelectric element 7 assumes induction at points between a resonant point and a non-resonant point.

**[0013]** Two buffers 16a and 16b are respectively connected to the two electrode pattern groups 12a and 12b of the piezoelectric element 7 in an independent fashion. The vibrator 6 bonded with the piezoelectric element 7 and the two capacitors 18 and 19 cooperatively form a resonator circuit. An inverter 15a and resistance 14a forms an inversion amplifier circuit to invert and amplify a signal from the resonator circuit and sends it back to the resonator circuit, thereby sustaining oscillation.

**[0014]** Here, the inverter 15a and the two buffers 16a and 16b are in a tri-state configuration which can provide a high impedance state, i.e. off output signal, on an output terminal depending on a signal input to a control terminal.

**[0015]** For example, turning off an output signal of any one buffer 16a or 16b enables switching rotation of between normal and reverse. Stop occurs by turning off an output signal of the inverter 15a or two buffers 16a and 16b (high impedance on the output terminal).

**[0016]** In the meanwhile, as shown above, the ultrasonic motor of the invention is driven by one standing wave. It is often a case that, in a vicinity of a resonant mode contributing to driving, other vibration modes occur that give no contribution to driving regardless of a magnitude of an oscillation force. This in many cases is due to a vibration mode having a same form as a vibration mode contributing to driving but different in node position with respect to the circumferential direction.

**[0017]** For example, if a drive signal is applied to the electrode pattern group 12a to cause a vibration mode as in Fig. 3C, there is often a case that a vibration mode be caused as in Fig. 3D wherein in a vicinity of a resonant point, a resonant point be caused orthogonal to that vibration mode (with phase deviation by 90 degrees in position). This unwanted vibration mode varies in magnitude and frequency depending on a vibration mode used, electrode pattern on the piezoelectric element 7, shape of the vibrator, and so on. Particularly for a vibrator shape as in the present embodiment, the magnitude and resonant frequency of unwanted vibration is greatly affected by the shape of vibrator disk and protrusions 6a. If the bending moment at the protrusion 6a has a natural oscillation frequency approaching a natural oscillation frequency of target vibration, the unwanted vibration mode increases. Accordingly, the protrusions 6a must be set in height and width with attention paid to those factors. By optimizing these design parameters, the resonant point for such an unwanted vibration mode is increased higher than a resonant point of a target vibration mode. For example, as shown in Fig. 3 the electrode pattern on the piezoelectric element 7 is optimized to reduce an oscillation force of an unwanted vibration mode, i.e. admittance and electromechanical coupling coefficient, smaller than those of the target vibration mode. This suppresses the amplitude of an unwanted

vibration mode and facilitates self-oscillation in a target mode. Also, adjustment is made on values of the elements forming the filter, such as capacitors 18 and 19 and resistance 17a, in order for causing oscillation between a resonant point of a target vibration mode and a resonant point of an unwanted vibration mode, thereby setting an oscillation frequency to stably oscillate at the target vibration mode.

**[0018]** At a higher frequency than a resonant point as a boundary, the mechanical amplitude of vibrator 6 gradually decreases. At a lower frequency than the resonant point, it greatly decreases and the effect of vibration mode becomes extremely small. Particular also from a hysteresis characteristic, unique to piezoelectric, the mechanical amplitude decrease is abrupt at a lower frequency than the resonant point. Accordingly, by optimizing structural design parameters for the ultrasonic motor 3 as shown above, as shown in Fig. 1 a second resonant point where an unwanted vibration mode will occur is made higher than a first resonant point where a target vibration mode is to be caused. Furthermore, by optimizing a circuit constant, a self-oscillation is caused between the resonant point for causing a target vibration mode and the second resonant point for an unwanted vibration mode, particularly in a region 100 where the phase is greatly inverted. This provides stable oscillation and realizes an ultrasonic motor which is extremely low in effect of an unwanted mode and stable in operation and high in efficiency.

**[0019]** The explanation was herein made on the example utilizing the Colpitts oscillator circuit as a self-oscillator circuit. Alternatively, a vibration feed-back type oscillator circuit may be used as shown in Fig. 5 wherein a detection electrode 12d is provided separately from the drive electrode 12a or 12b to feed back a detection signal to the drive electrode 12a or 12b through amplifier circuits 14b, 15b and 14c, 15c thereby sustaining oscillation. Also, the ultrasonic motor 3 is not limited in structure or driving principle to the one shown herein. That is, the invention is applicable for a case that a resonant point not contributing to driving exists in the vicinity of a resonant point having a resonant mode contributing to driving the ultrasonic motor 3.

**[0020]** In resonance, self-oscillation is easy to occur where admittance and electromechanical coupling coefficient are both high. Particularly where admittance is high, a large detection signal is obtained from a detection electrode in a self-oscillator circuit of a vibration feed-back type as shown in Fig. 5, facilitating oscillation. Meanwhile, where electromechanical coupling coefficient is high, it is possible to obtain a wide frequency range 100 that the piezoelectric element 7 is inductive thus facilitating oscillation in a Colpitts self-oscillator circuit as was shown in Fig. 4 and enabling oscillation over a wide frequency range.

**[0021]** Figs. 6A to 6C shows a driving principle of an ultrasonic motor of another embodiment according to the invention. This ultrasonic motor is basically the same

in basic structure as that described before.

Two piezoelectric elements 7c and 7d herein are bonded together as shown in Fig. 6A which are different in polarization direction at an interval for example of a half wavelength. In one element, the hatched part and the non-hatched part are opposite in polarization direction with respect to a thickness direction. That is, bonding is made such that the protrusions 6a are positioned at a center of each polarization region for one piezoelectric element 7c and at a boundary of adjacent polarization regions for the other piezoelectric element 7d. Herein, the application of a voltage signal with a predetermined frequency to the piezoelectric element 7c causes a vibration mode 400 to vertically vibrate the protrusions 6a. If a voltage signal with a predetermined frequency is applied to the piezoelectric element 7d, a vibration mode 500 is caused to vibrate the protrusions left and right. Consequently, if the piezoelectric elements 7c and 7d are applied with respective voltage signals, two vibration components 400, 500 are combined to move the moving member 8 rightward as shown by the arrow in Fig. 6B. Next, the piezoelectric elements 7c and 7d are applied with voltage signals different in phase for example by 180 degrees, two vibration components 400 and 600 are combined thereby moving the moving member leftward as shown by the arrow in Fig. 6C.

**[0022]** In the case that two vibration modes are utilized to structure a motor in this manner, a difference occurs not a little between the two vibration resonant frequencies. The resonant frequency varies depending on a shape of the vibrator 6, an electrode pattern on the piezoelectric element 7 and the like. In the case that the ultrasonic motor is driven by self-oscillation in this manner, these design parameters are optimized to bring these two resonant points 22 and 23 as close as possible as shown in Fig. 7. Furthermore, the circuit constant of a self-oscillator circuit is adjusted for self-oscillation at a higher frequency than the two resonant points 22 and 23.

**[0023]** Although the ultrasonic motor shown in the present embodiment utilizes two vibration components, displacement abruptly decreases at a low frequency than the resonant point as was shown before.

**[0024]** Meanwhile, hysteresis occurs in the vicinity of the resonant point. Accordingly, self-oscillation if caused at a higher frequency than the two resonant points 22 and 23 makes possible to effectively utilize two vibration modes and hence realize an ultrasonic motor high in efficiency, stable in oscillation and high in reliability. The oscillator circuit requires a large circuit loop gain and phase rotation being in a multiple of 360 degrees. As shown in Fig. 7 by reducing a frequency difference between the two vibration resonant points 22 and 23 smaller than a frequency difference between a higher resonant point 23 and an anti-resonant point thereof, the region 200 where phase greatly changes (about 180 degrees) broadens. This enables stable self-oscillation, widens a variable range of oscillation frequency and fa-

cilitating to adjust or change motor characteristics such as rotation speed. This is particularly effective for the case of utilizing a Colpitts oscillator circuit as was shown in Fig. 4, because the electric characteristic of piezoelectric element 7 becomes inductive and oscillation frequency has a difference 200 between a resonant point that phase changes by 180 degrees and an anti-resonant point. Fig. 8 shows an admittance characteristic for a case that two resonant points are conversely distant. In this manner two resonances are separated and a phase-inverting region is completely separated into two. Accordingly, particularly where utilizing a Colpitts oscillator circuit, if oscillation is caused at a lower one of the resonant frequencies, any one of the vibration modes can only be utilized, thus reducing the efficiency of the ultrasonic motor 3.

**[0025]** The example using the piezoelectric element structure as in Fig. 6 was herein shown on the case of using the two vibration modes. However, the invention is not limited to this. Further, the motor structure is not limited to this. For example, it is also possible to use one as shown in Fig. 9 utilizing a resultant vibration 900 of expansion vibration 700 and bending vibration 800 on a rectangular plate. Herein, a drive signal is applied to a piezoelectric element 7e polarized in a same thickness direction P throughout a surface and having an electrode 12h over the entire surface thereof to provide expansion vibration 700. Further, a piezoelectric element 7f having four-divided electrodes 12i, 12j, 12k and 12l on at least one surface and polarized in a same thickness direction throughout a surface so that a signal can be applied only to the diagonally-positioned electrodes 12i, 12l or 12j, 12k to principally cause bending vibration 800.

**[0026]** Furthermore, in a case of using vibration 400 and 700 having displacement in a contact pressure direction of the moving member 8 and vibrator 6 as were shown in the above two examples, a resonant point of that vibration is positioned at the resonant point 23 higher in frequency of the two resonant points 22 and 23 of Fig. 7. This makes it possible to produce a reacting force against an application force by the moving member 8, generating a large torque.

**[0027]** Fig. 10 shows a block diagram of a further embodiment wherein the ultrasonic motor of the invention is applied to an electronic appliance.

**[0028]** The present electronic appliance is characterized by having a vibrator 6 as described before, a moving member 8 to be driven by the vibrator 6, pressurizing means 4 for applying a contact pressure to the moving member 8 and vibrator 6, a transmission mechanism 26 for interacting with and moving the moving member 8, and an output mechanism 27 to move based on the movement of transmission mechanism 26.

**[0029]** The transmission mechanism 26 herein uses, for example, a transmission wheel, such as a gear or friction wheel. A direct output mechanism may be provided with the transmission mechanism 26 omitted. The

output mechanism 27 uses, for example, for a indicator device or electronic timepiece a pointer, a pointer drive mechanism, display board such as of a calendar, or a display board drive mechanism, for a copier or printer a mirror for changing laser direction, for a camera or video camera a shutter drive mechanism, an aperture drive mechanism, a lens drive mechanism, a film winding mechanism or the like, for a measuring instrument or manufacture equipment or sensor utilizing laser or light

5 a slit sheet or filter to shade, transmit light or pass a particular wavelength of light, for an acoustic device volume control or the like a contact mechanism or gap plate to vary a resistance or capacitance value, and for a hard disk or optical disk a pick-up drive mechanism.

10 **[0030]** Meanwhile, if an output shaft is mounted on the moving member 8 to provide a structure having a power transmission mechanism to transmit torque through the output shaft, a drive mechanism can be realized by the ultrasonic motor itself.

15 **[0031]** As discussed above, the use of the ultrasonic motor for a drive source of an electronic appliance makes possible reduction of apparatus size and power consumption, improvement of responsibility and positioning dissolving power, and use in a magnetic field or

20 vacuum.

25 **[0032]** Furthermore, the use of a self-oscillation driving as in the invention would achieve drive-circuit size reduction and ultimately apparatus overall size reduction and cost reduction. It is possible to realize an ultrasonic motor which stably causes self-oscillation without occurrence of abnormal oscillation, and further an ultrasonic motor which improves reliability of an appliance mounting with the ultrasonic motor but is less in characteristic change. Furthermore, realized are an ultrasonic

30 motor having high torque, and an electronic appliance to be driven by an ultrasonic motor to which the invention is applied.

35 **[0033]** The foregoing description has been given by way of example only and it will be appreciated by a person skilled in the art that modifications can be made without departing from the scope of the present invention.

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#### 45 Claims

1. An ultrasonic motor (3) having a vibrator (6) having a piezoelectric element (7) to be vibrated to fractionally drive a moving member (8), the ultrasonic motor is characterised in that:

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the vibrator has a first resonant point (2), and a second resonant point (1) that is same in form as vibration mode to occur on the vibrator as the first resonant point but different in position of a node,  
wherein the second resonant point is higher in resonant frequency than the first resonant

point.

2. An ultrasonic motor according to claim 1, having a self-oscillator circuit configured by an amplifier circuit (13),  
self-oscillation driving being made between a resonant frequency of the first resonant point and a resonant frequency of the second resonant point. 5
3. An ultrasonic motor according to claim 1, wherein the first resonant point has an admittance higher than an admittance at the second resonant point. 10
4. An ultrasonic motor according to claim 1, wherein the first resonant point has an electromechanic coupling coefficient higher than electromechanical coupling coefficient at the second resonant point. 15
5. An ultrasonic motor having a vibrator (6) having a piezoelectric element (7) to be vibrated to frictionally drive a moving member, the ultrasonic motor characterised in that:  
the moving member is fractionally driven by combining together two different modes occurred on the vibrator, and the vibrator being self-oscillation driven at a resonant frequency higher than resonant points where the two vibration modes are to be caused. 20
6. An ultrasonic motor according to claim 5 wherein, of the resonant points to cause the two vibration modes, a vibration mode to occur at a resonant point (22) higher in frequency is a vibration mode to give displacement in a direction of contact pressure of the moving member and the vibrator. 30
7. An ultrasonic motor according to claim 5, wherein a difference between resonant frequencies at the resonant points to cause the two vibration modes is smaller than a frequency difference (200) between a resonant point higher in frequency and an anti-resonant point thereof. 40
8. An electronic appliance having an output mechanism for producing an output motion including, an ultrasonic motor as claimed in any one of claims 1 to 4 for driving the output mechanism to produce the output motion. 45
9. An electronic appliance having an output mechanism for producing an output motion, including an ultrasonic motor as claimed in any one of claims 5 to 7 for driving the output mechanism to produce the output motion. 50

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FIG. 1

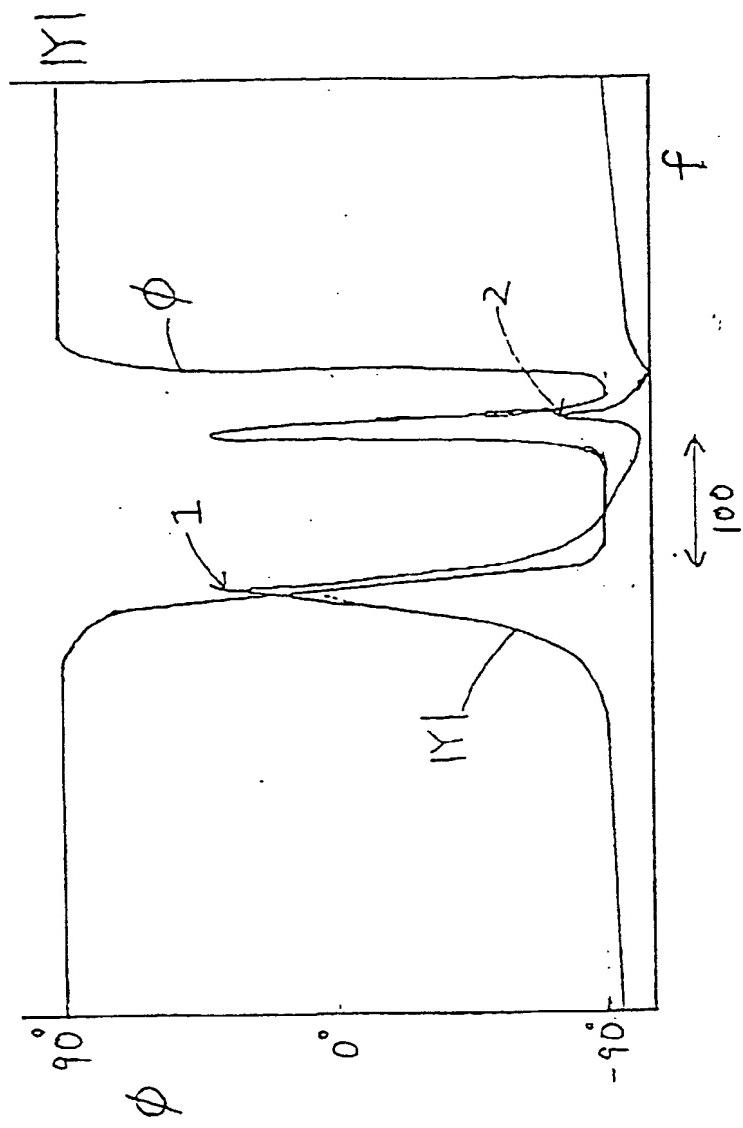


FIG. 2

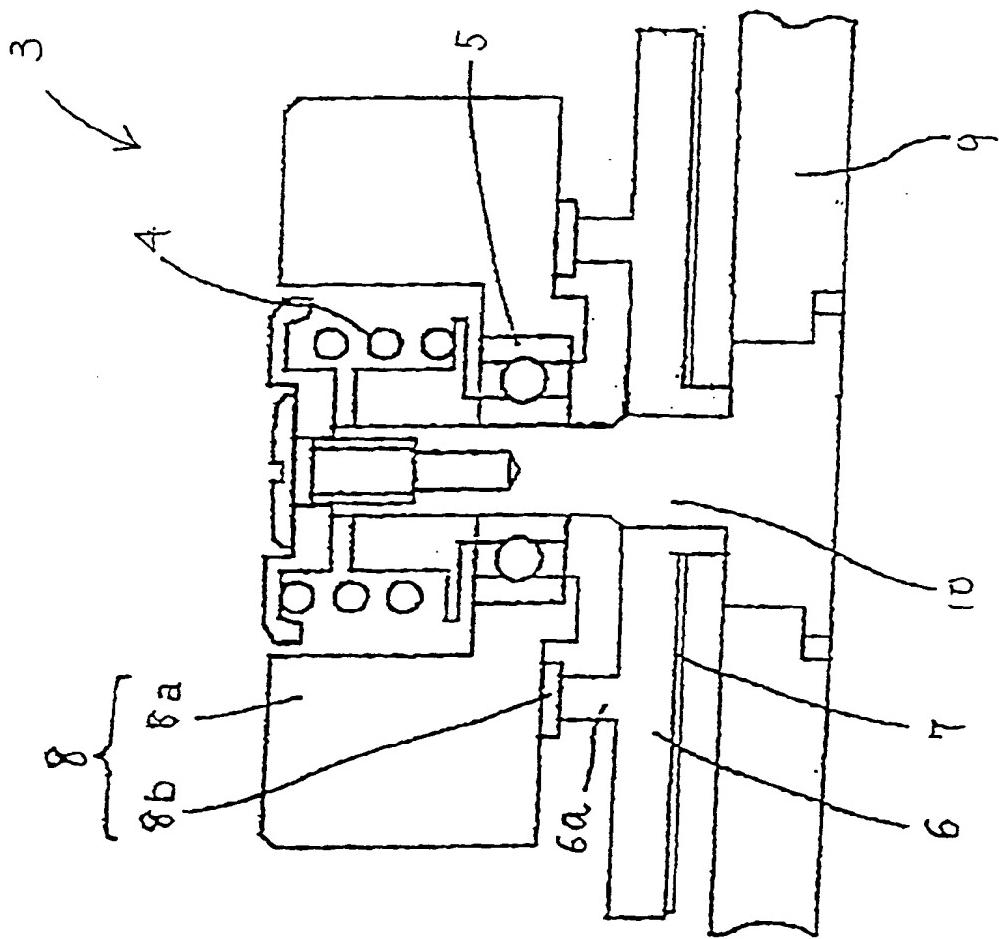


FIG. 3A

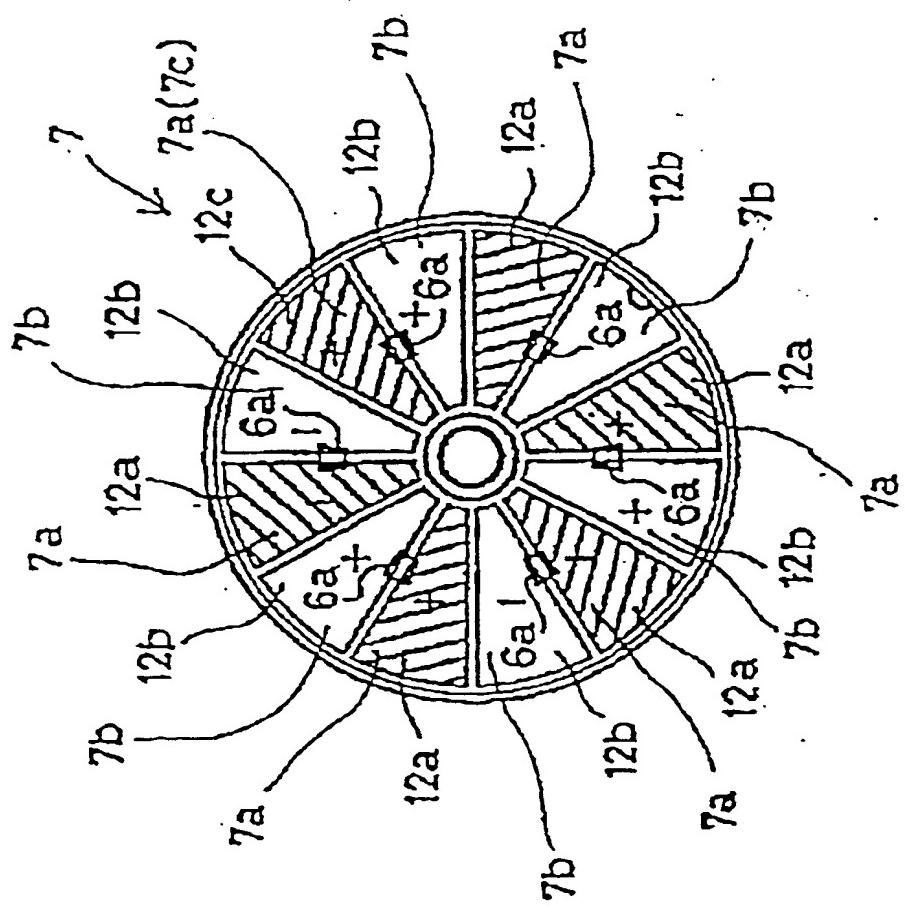


FIG. 3B

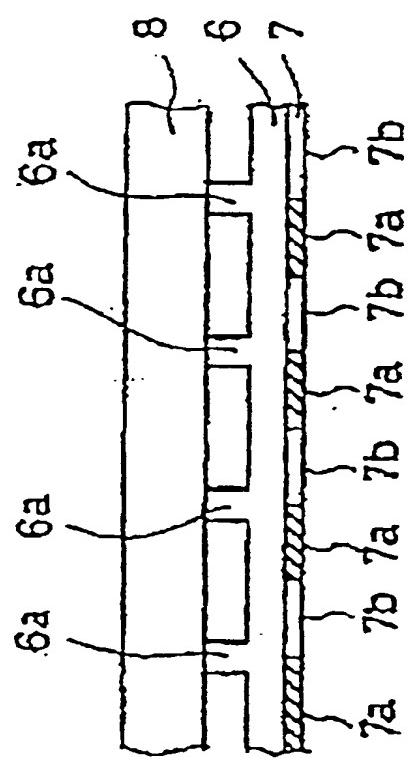


FIG. 3C

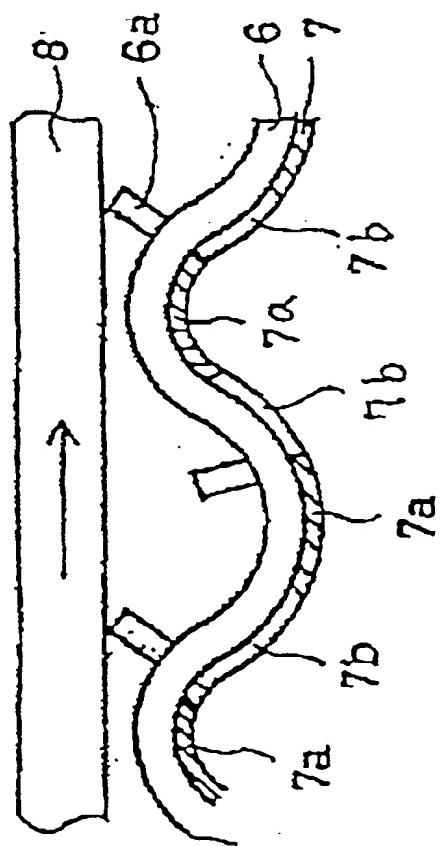


FIG. 3D

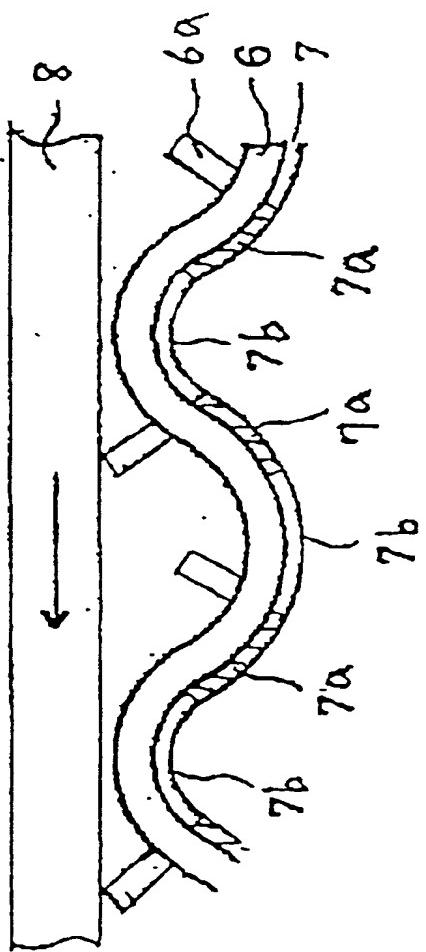


FIG. 4

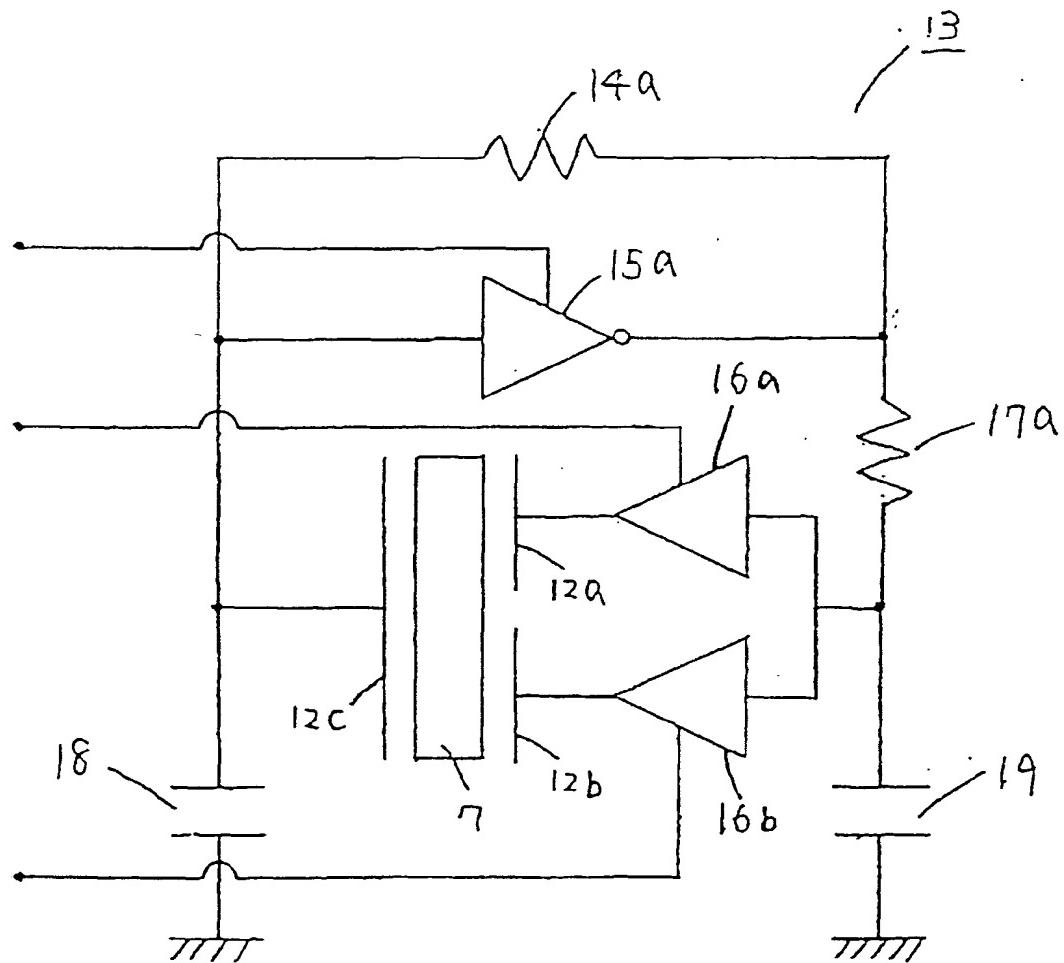


FIG. 5

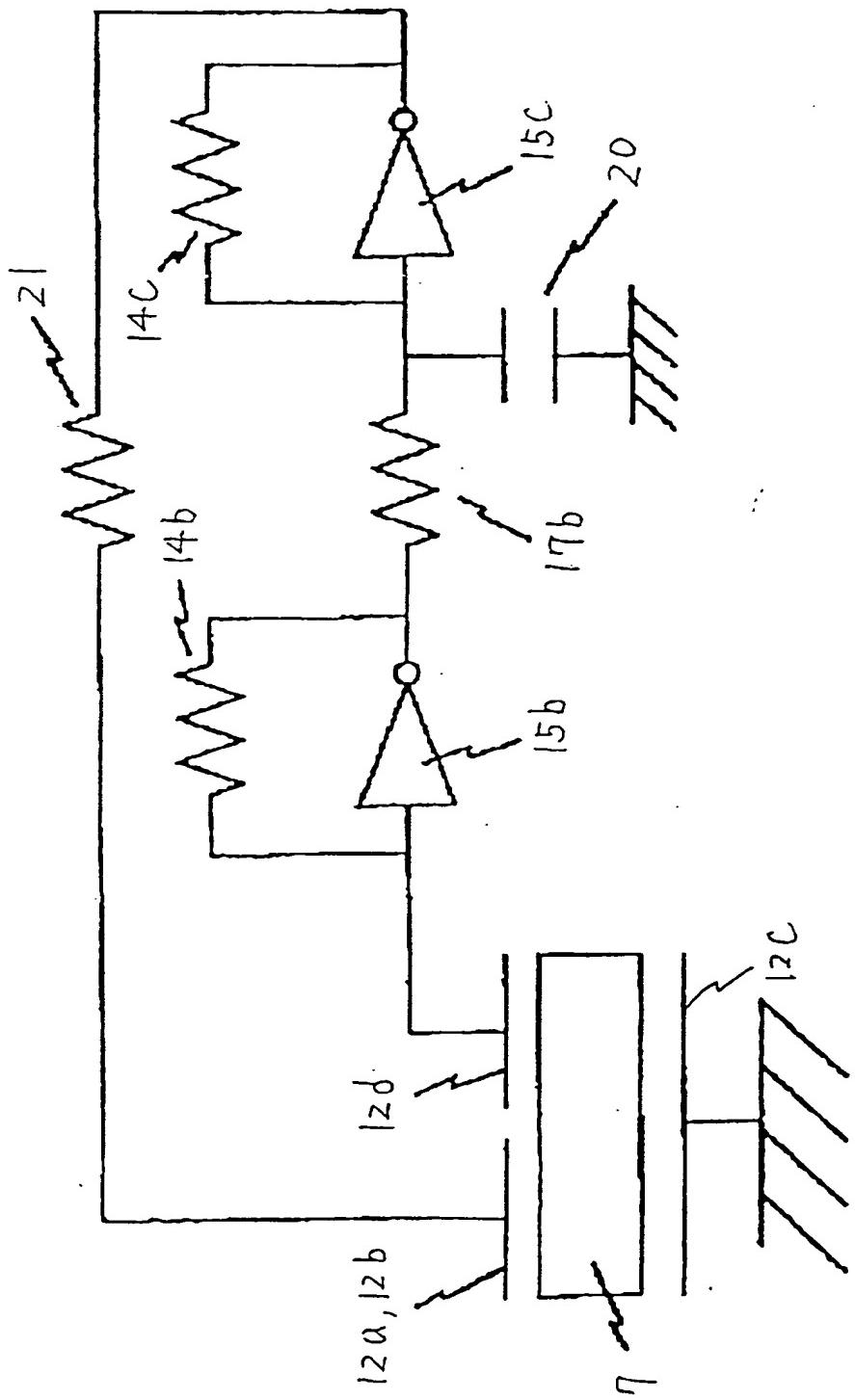


FIG. 6A

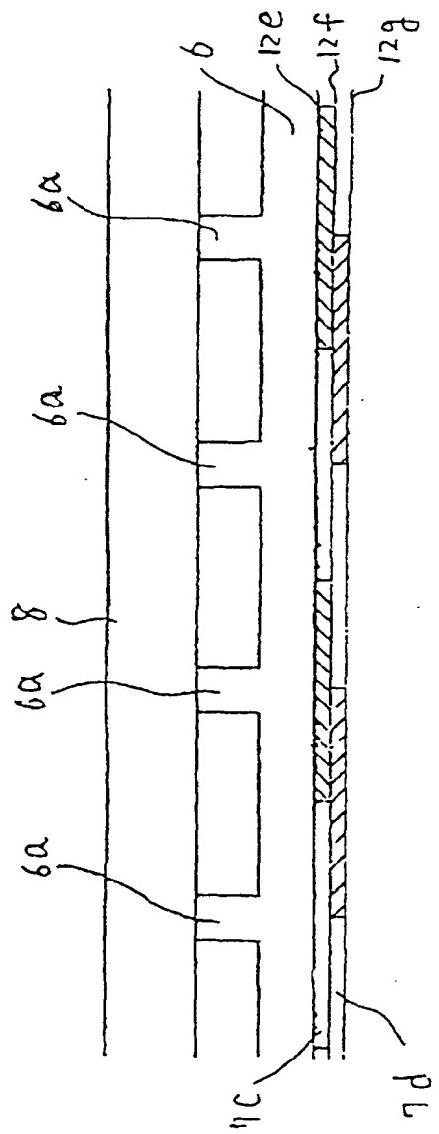


FIG. 6B

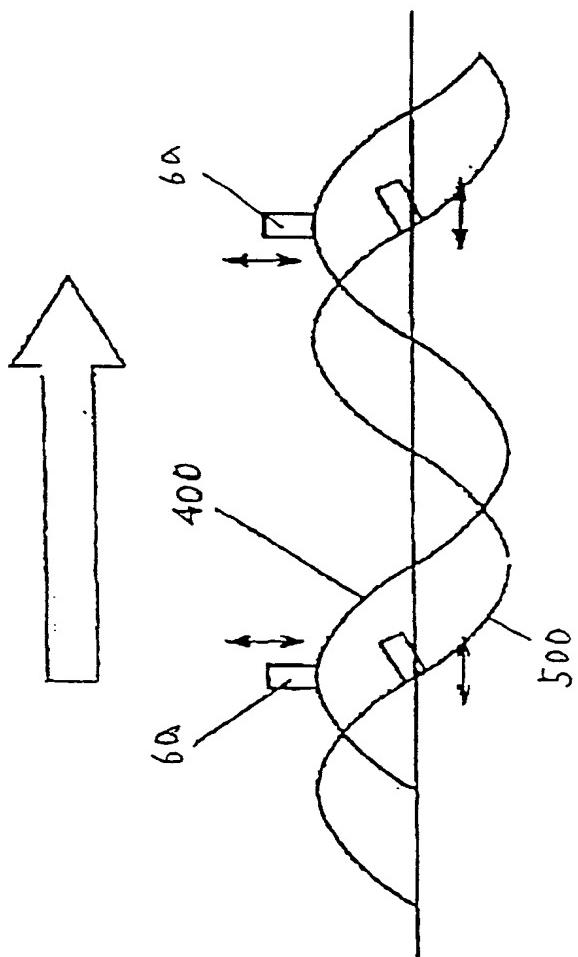


FIG. 6C

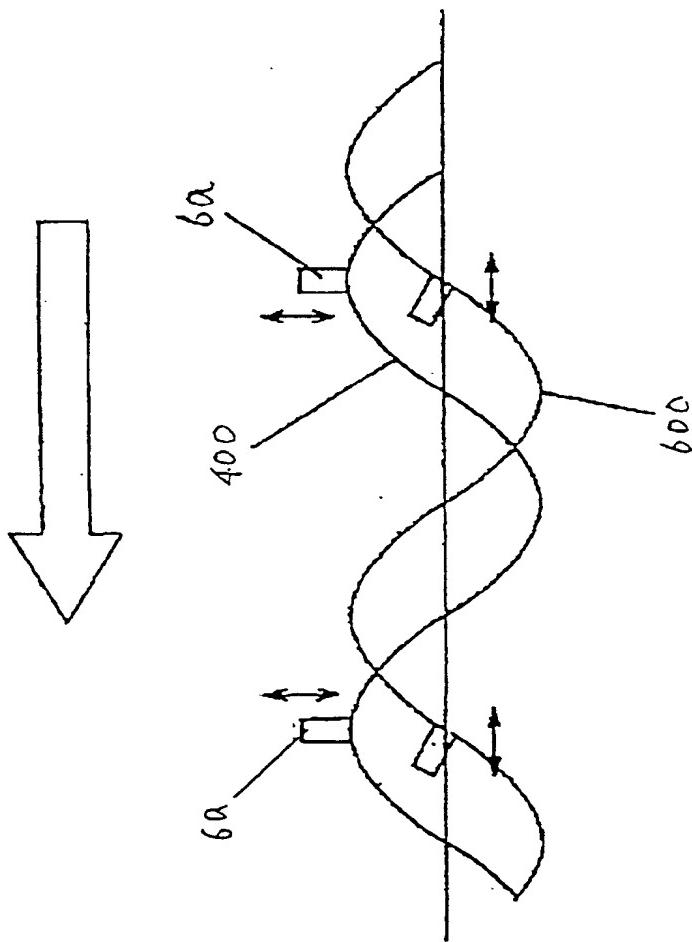


FIG. 7

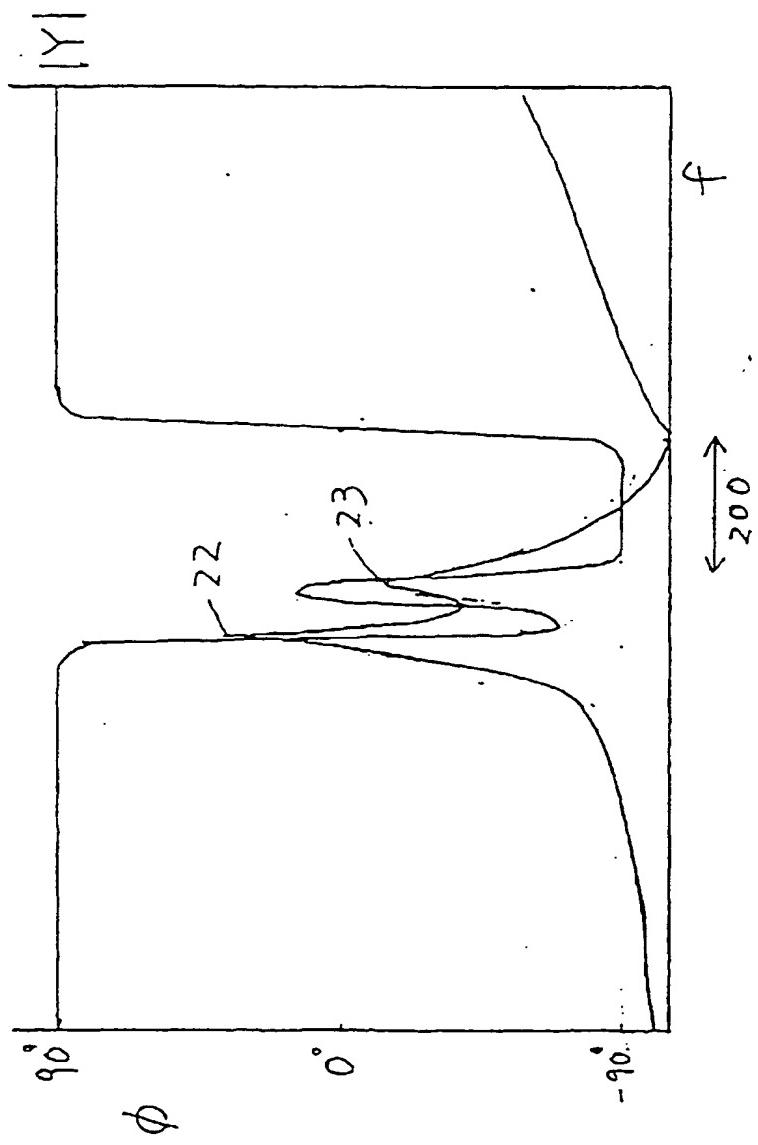


FIG. 8

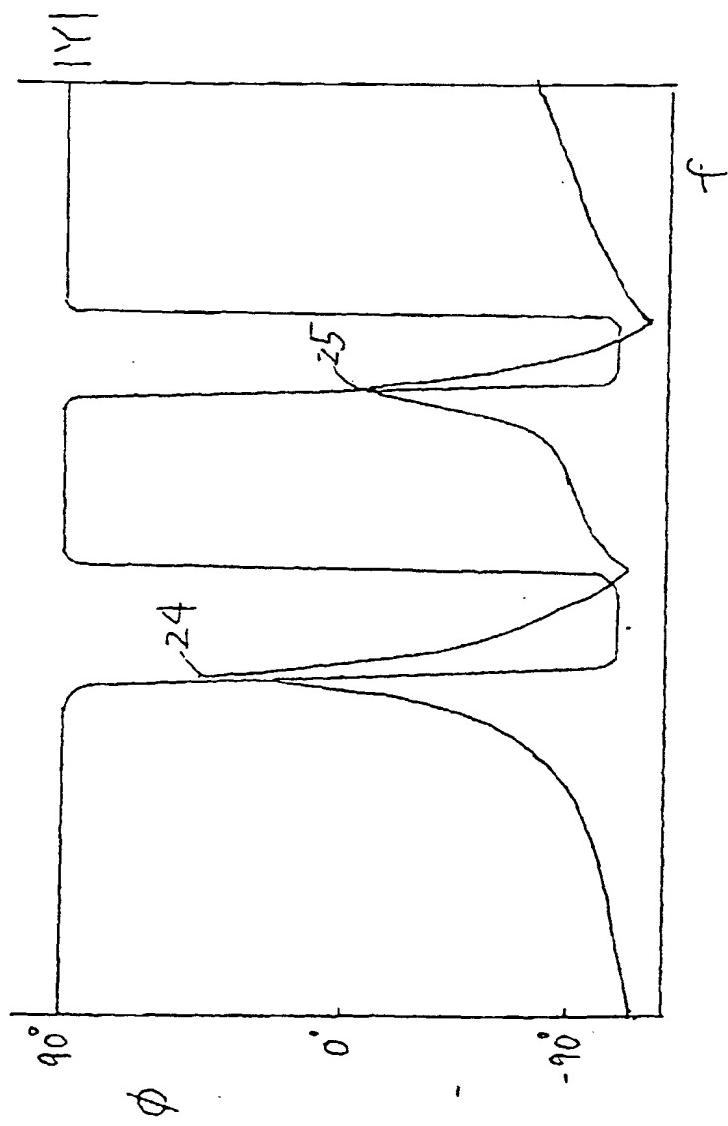


FIG. 9

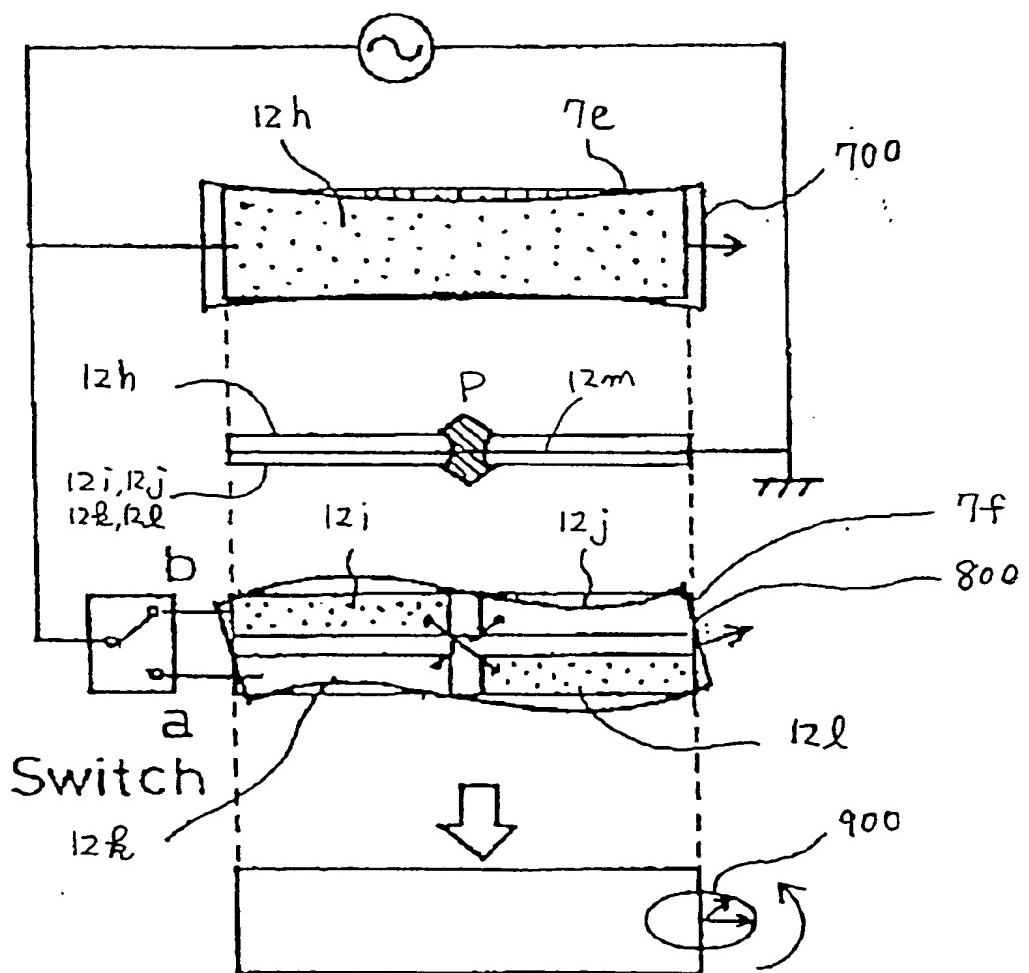
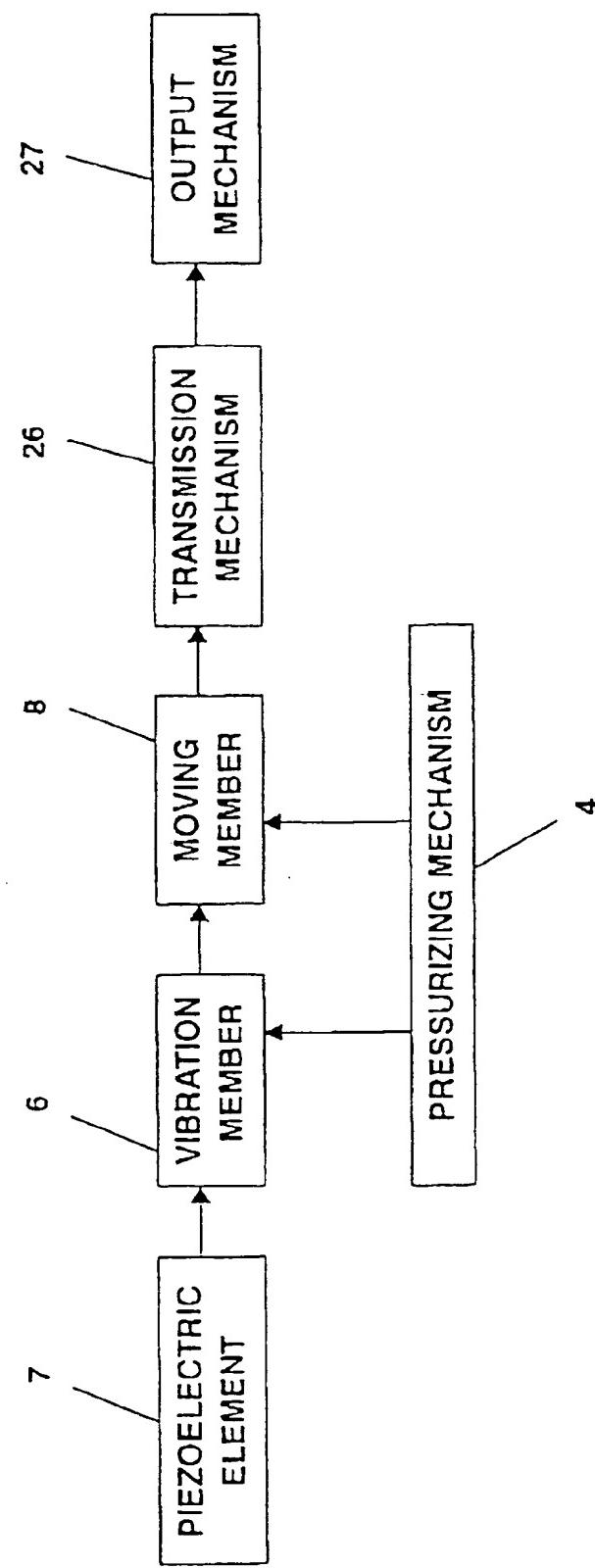


FIG. 10





European Patent  
Office

## EUROPEAN SEARCH REPORT

Application Number  
EP 00 30 2468

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	US 4 882 500 A (IIJIMA TAMOTSU) 21 November 1989 (1989-11-21) * column 8, line 43-61 *	1	H01L41/09
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The present search report has been drawn up for all claims			
Place of search	Date of completion of the search	Examiner	
THE HAGUE	22 June 2000	Pelsers, L	
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone	T : theory or principle underlying the invention		
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A : technological background	D : document cited in the application		
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**ANNEX TO THE EUROPEAN SEARCH REPORT  
ON EUROPEAN PATENT APPLICATION NO.**

EP 00 30 2468

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on  
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22-06-2000

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